

ESTIMATING SOIL WATER CONTENT ON NATIVE RANGELAND*

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ABSTRACT

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A model for estimating soil water content on native rangeland was tested at Sidney, Montana. Based on the Penman combination method for estimating potential *ET*, the model includes factors to account for crop development, limiting soil water content, and increased evaporation after rain. The model gave reasonable estimates of actual soil water conditions within a 15% limit suggested as being practical for rangeland management purposes.

INTRODUCTION

Livestock production is the largest industry in Montana and accounts for about \$250 million of the gross income in the state (Montana State Soil Conservation Committee, 1970). Approximately 96% of the livestock is raised on open rangeland (U.S. Department of Agriculture, 1971); therefore, sound range management practices are important. Dry matter production and carrying capacity of rangeland are linked very closely to soil water availability. Fluctuating forage supplies, because of variations in rainfall, necessitate prompt adjustments in grazing pressure to avoid range deterioration.

Information on variations in the factors of the water balance, such as water surplus and deficit, actual evapotranspiration, and soil water content, is fundamental to sound planning and development of grassland agriculture and management (Mather, 1959).

Knowledge of soil water content, coupled with rainfall probability statements could be used by agencies such as the USDA Statistical Reporting Service in its regularly issued bulletins listing soil water, crop, and range feeding conditions.

Jensen (1969, 1972) and Jensen et al. (1970, 1971) have successfully used predictive methods in estimating irrigation requirements. Heermann and Gardner (1970) used a similar model to predict evapotranspiration from dryland sorghum. Recently, Ritchie (1972)

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developed a model to predict evapotranspiration from row crops with incomplete ground cover in a subhumid climate. All these predictive methods include plant factors to convert potential evapotranspiration to actual evapotranspiration.

Our objective, as a first step towards a practical management tool for native rangeland resources, was to develop a simple method to estimate soil water content on native range at weekly intervals during the growing season.

METHODS

Potential ET

The method consists of first estimating daily atmospheric potential evapotranspiration according to the Penman (1963) combination method. The daily values are averaged and used in the calculations to obtain weekly soil water contents. The basic equation used was:

$$ET_o = \frac{\Delta}{\Delta + \gamma} (R_n - G) + \frac{\gamma}{\Delta + \gamma} (15.36)(1.0 + 0.0062W)(e_s - e_d) \quad (1)$$

where ET_o = potential evapotranspiration in langley; Δ = the slope of the saturation vapor pressure–temperature curve, d_s/dT ; γ = the psychrometric constant; e_s = saturation vapor pressure at mean air temperature in mbar; e_d = saturation vapor pressure at mean dew point temperature in mbar; W = total daily wind run in km measured at the 2-m height; R_n = daily net radiation in langley; and G = daily soil heat flux in langley.

Daily climatic parameters measured and used were solar radiation, maximum and minimum air temperatures, mean dew point temperature, and total wind run at 2 m. In 1970, R_n was estimated from a locally derived empirical relation between solar and net radiation as follows:

$$R_n = 0.627 (1 - \alpha) R_s + 0.518$$

A seasonal average value of 0.19 was used for albedo, α . Clear-day solar radiation was estimated from available solar radiation data. In 1971 and 1972, net radiation was measured with a miniature net radiometer (Fritschen, 1965). Soil heat flux, less than 10% of net radiation (Aase and Wight, 1970), was ignored in the calculations, resulting in errors on the order of 1% in soil water estimates.

Actual ET

Potential ET was converted to actual evapotranspiration, ET_a , as follows:

$$ET_a = ET_o \times P_a$$

where P_a is an adjusted plant growth coefficient. ET_a is subtracted from the previously calculated soil water content, and any rainfall is added to arrive at the current soil water content. It is necessary to make one soil water content measurement in the spring to establish the initial boundary condition.

Plant growth coefficient

A plant growth coefficient, P , was determined from a growth curve using average up-stretched leaf lengths of the predominant forage species from 3 years of data (1967, 1968, and 1969). Complete ground cover is never attained under existing conditions. From observations on site and from study of photographic records of vegetative growth, we arrived at a maximum ground cover estimate of about 50%. For this reason, a maximum value of $P = 0.5$ was assigned to correspond to maximum height of the growth curve (Fig.1). Day 1, for all practical purposes, corresponds to 1 April. The curve is extrapolated past the 150th day (about August 25).

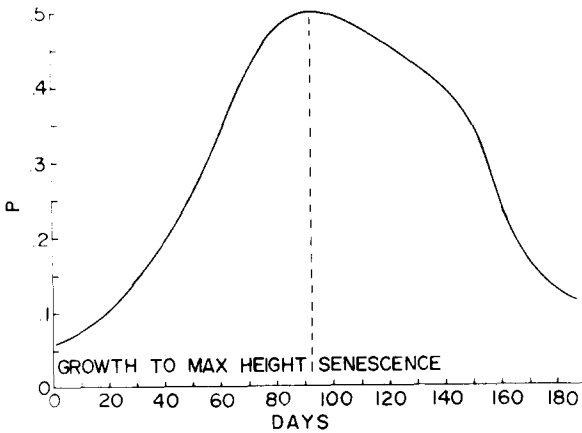


Fig.1. Seasonal crop coefficient for native range vegetation near Sidney, Montana.

Under semi-arid rangeland conditions, lack of soil water is usually limiting plant growth; therefore, it is necessary to account for the limiting soil water content in the calculation of actual evapotranspiration. It is also necessary to account for an increase in ET after rain; consequently, the plant growth coefficient, P , is modified by limiting soil water content and rainfall. The adjusted plant growth coefficient is then expressed as:

$$P_a = P \times W_1 + E_r \tag{2}$$

where W_1 is the soil water coefficient and E_r is extra evaporation after rain (Jensen, 1972).

Soil water coefficient

The soil water coefficient, W_1 , was determined from the logarithmic relationship:

$$W_1 = \log (100 w_a/w_c + 1)/\log 101 \tag{3}$$

where w_a = water in the profile at a given time minus that at permanent wilting point; and w_c = water in the soil at field capacity minus that at permanent wilting.

Field capacity (25.9% by volume) and permanent wilting point (11.1% by volume), based on a 150-cm profile, were derived from 5 years of field measurements of soil water content. A 150-cm soil water profile was chosen because it corresponded to observed maximum depth of soil water extraction. We assumed that the estimated water content could neither exceed field capacity nor fall below the wilting point. We further assumed that ET_a would not exceed 90% of ET_o (Heermann and Gardner, 1970).

Increased ET after rain

A similar expression to that of Jensen (1972) was adopted to express increased evaporation after rain in each weekly period considered:

$$E_r = (0.9 - P) \times 0.5 \quad (4)$$

Any weekly rain of 3 mm (1/8 inch) or less was not considered in the above equation and was added directly to the calculated evapotranspiration.

Test site

The model was tested on native rangeland near Sidney, Montana (47°45'N 104°10'W) on a Williams loam (fine-loamy, mixed family of Typic Argiborolls). Annual precipitation (1948–72) averages 34 cm with about 80% received during April through September. The area was described according to the Soil Conservation Service range classification system as a sandy glaciated plains range site in a 25- to 36-cm precipitation zone with the range in fair to good condition (USDA–SCS, 1971). Vegetation was typically mixed prairie including western wheatgrass (*Agropyron smithii* Rydb.), needle-and-thread (*Stipa comata* Trin. and Rupr.), prairie junegrass (*Koeleria cristata* (L.) Pers.), threadleaf sedge (*Carex filifolia* Nutt.), and blue grama (*Bouteloua gracilis* (HBK) Lag.) as the predominant species. Basal cover determined by the point method (National Research Council, 1962) was about 13%, and foliar density (counting all foliar hits) was about 23%.

Three access tubes were installed, and the model was tested against soil water measured by the neutron method to a depth of 150 cm. The initial soil water was measured on 4 May in 1970, 13 April in 1971, and 18 April in 1972 with respective soil water contents of 32.3, 24.4, and 33.4 cm in the 150-cm profile.

RESULTS AND DISCUSSION

Daily averages of weekly ET_o , ET_a , and rainfall are shown in Fig.2. Seasonal (April through September) rainfall was 31.7, 22.6, and 35.8 cm in 1970, 1971, and 1972, respectively. The seasonal 24-year average rainfall is 27.4 cm. ET_o obviously tends to follow the rainfall pattern. Except in dry periods, ET_a tends to parallel ET_o . A noteworthy feature is the low ET_o in 1972. Rainfall in 1972 was 31% higher than the 24-year average, and it was

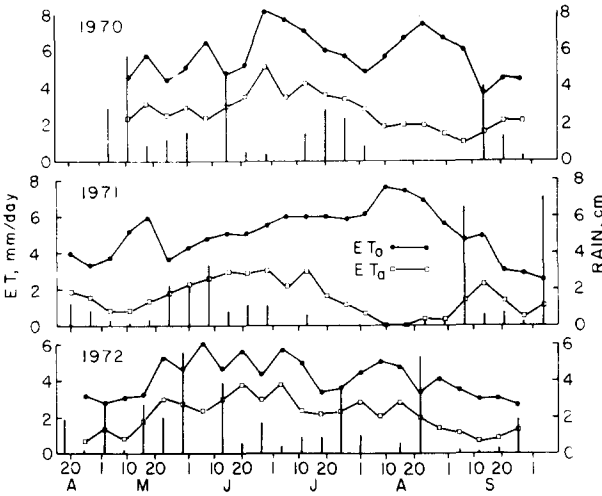


Fig.2. Weekly averages of Penman estimate of potential evapotranspiration (ET_0), calculated actual evapotranspiration (ET_a), and total weekly rainfall.

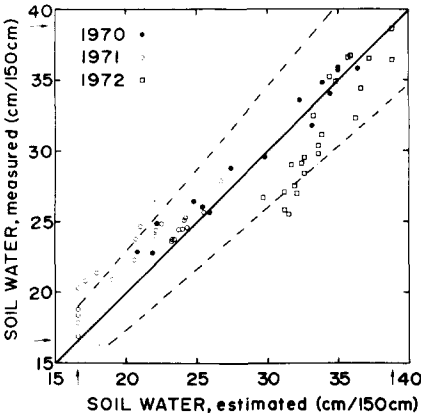


Fig.3. Calculated soil water compared with measured soil water content for the 1970, 1971, and 1972 seasons. The solid line is the 1:1 line; the dashed lines are the 15% lines; the arrows indicate wilting point and field capacity.

exceptionally well distributed over the season. Consequently, ET_0 was lower than in either of the other 2 years.

Test results for the 3 years are shown in Fig.3. Calculated soil water content is shown in relation to measured soil water content. We felt that estimates falling within 15% of actual soil water content would be a satisfactory measure and would be of practical value for rangeland managers. Consequently, 15% lines are dashed on either side of the 1:1 line on the figure.

The data points are well distributed over the whole range of soil water content from wilting point to field capacity, and the calculated and measured values agree reasonably

well. During the very dry, late summer of 1971, the model tended to underestimate the soil water. Commencing with the period ending 3 August 1971, the model estimated five consecutive weeks of zero available soil water. There were no zero estimates of available soil water in 1970 or 1972.

During late season of 1972, the model overestimated soil water content, and the estimates outside the 15% line occurred after the 150th day. Because of the favorable growing conditions, plants remained green and viable long after they usually cease growth, and the extrapolation past day 150 on Fig.1 does not fit the conditions of this extraordinary year. The extrapolation of the plant cover coefficient should be adjusted upwards, and by so doing, the overestimates in 1972 would be adjusted downwards to fall within the 15% line.

Correlation of all estimated and measured soil water contents in Fig.3 yielded a linear relationship ($X_2 = 0.77 X_1 + 6.37$) with $r = 0.939$.

We feel the model can be a useful tool in the hands of range managers. Measured environmental parameters used in the calculations should be useful over a large area of the semi-arid rangelands with similar climate and plant cover, and they are reasonably easy to obtain. The logarithmic relationship for the soil water coefficient was chosen as being most suitable for the local conditions; however, it may be necessary to adjust this coefficient.

The concept of a crop coefficient has been discussed by Blaney (1959), Jensen (1969, 1972), Jensen et al. (1970, 1971), Ritchie and Burnett (1971), Ritchie (1972), and others. The plant cover coefficient used here is based on a simple concept of growth curves of major species in a complex plant community (over 100 species identified), and no extensive measurements of fairly complex parameters such as leaf area indices, etc., need be taken. However, based on observations of unusual growth as in 1972, the extrapolated part of the plant cover coefficient curve may particularly need adjusting.

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